AD-764 056

ANALYSIS OF THE CONDITION OF ECHO TOWER AZORES FIXED ACOUSTIC RANGE, AFTER ONE YEAR AT 1500 FEET OF DEPTH

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Prepared for:

Naval Underwater Systems Center

May 1973

AD 764056

Technical Note N-1284

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Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Civil Engineering Laboratory Port Hueneme, California 93043	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

ANALYSIS OF THE CONDITION OF ECHO TOWER, AZORES FIXED ACOUSTIC RANGE, AFTER ONE YEAR AT 1500 FEET OF DEPTH

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final

5. AUTHOR(S) (First name, middle initial, last name)

James F. Jenkins

6. REPORT DATE May 1973	7a. TOTAL NO. OF PAGES ~~22~~ 25	7b. NO. OF REFS 0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) TN-1284
b. PROJECT NO. 52-021	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES Details of illustrations in this document may be better studied on microfiche.	12. SPONSORING MILITARY ACTIVITY Naval Underwater Systems Center New London, CT 06320

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The condition of ECHO tower after a one year exposure to seawater at a depth of 1500 feet was analyzed immediately after removal, after five days exposure near the surface and after removal from the sea. The only areas of critical corrosion were several pits found on the antennas. These pits were recoated but failure of the repair coatings could result in tube penetration in as little as one year of additional exposure. Recommendations for modification of existing towers to increase their useful life, as well as that of future designs, are given.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Corrosion						
Sea water corrosion						
Towers						
Pitting						
Design criteria						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Unclassified

Security Classification

INTRODUCTION

On 12 July 1971, ECHO tower, the easternmost acoustic propagation studies tower of the Azores Fixed Acoustic Range (AFAR) was raised to the surface to repair damage incurred during emplacement and during a one year exposure to the seawater and bottom sediments at a depth of 1500 feet near Isla Santa Maria, Azores, Portugal.

The Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California, in cooperation with the Naval Underwater Systems Center (NUSC), New London Laboratory, New London, Connecticut, participated in the recovery of the tower in response to a request to analyze the deterioration of the tower. Observations of the tower were made at sea immediately after the tower was raised to the surface, at dockside prior to removal of the tower from the sea and, after being raised onto the dock, before and after refurbishment. This report is an analysis of these observations.

In order to best interpret the condition of structures exposed to seawater at depth, it is desirable to inspect them at depth. This is, in most cases, impractical. If the structure is inspected immediately after being brought to the surface and before its removal from the water its condition will closely approximate that at depth. After an extended period at or near the surface or after removal from the sea, the characteristics of the structure useful in analyzing its deterioration at depth will change significantly. In this analysis three inspections of the structure were made. The first was made while the structure was in the sea near the surface soon after it was retrieved from depth. The second was made approximately five days after retrieval before the structure was removed from the sea. The third inspection was made after the structure was removed from the sea five days after retrieval.

First Inspection

Approximately 12 hours after being retrieved from depth, an inspection of the upper portion of the tower was made while the tower was still completely submerged in seawater. A sketch of the tower is shown in Figure 1. Depth limitations limited this inspection to the portion of the tower above the center line of the sphere.

No fouling organisms were found on the upper portion of the sphere. The topcoat of paint on the sphere was lost over approximately 10% of its

surface leaving the zinc-rich-epoxy primer exposed. In addition, approximately 5% of the area of the upper portion of the sphere was covered with water-filled paint blisters. The areas of exposed primer were covered with a thin film of corrosion products which were sampled and found to be predominately $Zn(OH)_2$ by X-ray diffraction analysis. Only two small areas of rust staining were found on the upper portion of the sphere. One area was at a point of mechanical damage and had resulted in a pit nearly 1/8" deep. The rust stain in this area was tightly adherent and black in color. The other area of rust staining was under a mild steel washer found resting near the top of the sphere. The staining was from the washer which was covered with a tightly adherent black oxide. There was no failure of the paint coating associated with the washer.

The coating on the joint between the sphere and the steering carriage showed no damage. Some slight rust bleeding was noted at the faying surfaces in a few areas. The paint in these areas was not adversely affected. The only fouling on the steering carriage was a light, hair-like covering of hydroids, a common deep ocean animal. The paint coating on the steering carriage was intact except for areas on the inside of the flanges where the carriage stop housings were attached as shown in Figure 2. The steering carriage altitude and bearing shaft seals were free of attack or deposition. The altitude indicator scale and vernier were rusted in many areas but readable. The steering carriage identification plate was severely rusted.

The coating on the gas generator support frame was intact but there were a few rusted areas at the flange attachment of the support to the steering carriage. The gas generators were in excellent condition except for the expendable fittings used to start the generators. These fittings were made from aluminum alloys and/or stainless steels and were virtually destroyed by corrosive attack. The titanium cathode on the electrolytic generator was unattacked, the platinum gauze anode was unattacked but was partially clogged by hydroids.

The three antennas were virtually unattacked except for 12 small areas of rust staining on the compliant tubes. One such area on the low frequency antenna was probed during this inspection and revealed that underneath a thin, adherent black oxide scale there was exposed bare steel with underlying pits up to 1/16" deep. The gas connections between the ends of the compliant tubes and between the tubes and gas manifolds showed no visible attack on the nipples on the compliant tubes or on the tubing clamps. The antenna support arms had a few areas of rust at areas of mechanical paint damage. Two gooseneck barnacles, one identified as a species of Lepas the other as a species of Chonchoderma, were found on the middle frequency antenna. Later investigations indicated that these individuals had attached themselves to the antenna before its emplacement at depth but had survived for one year at depth. Their small size indicates that the low temperatures and dearth of food at depth severely retarded their growth.

The syntactic foam blocks of the foam tower and on the low frequency antenna were virtually unattacked. Hydroids covered the coatings on the blocks. The coatings used to paint the identifying "E" on the foam tower had flaked off but the underlying foam was unaffected. The main lifting eye at the top of the foam tower was covered with a moderately adherent reddish brown rust.

Second Inspection

After being towed at low speed to dockside the tower was again inspected in order to note any changes in the condition of the tower after being exposed to surface waters for five days and to inspect the portion of tower beneath the sphere which was at a shallow depth, the tower now being horizontal.

The shock absorbers at the tower base were moderately rusted and were covered with a loosely adherent film of flaky red rust. All four hardened tips located at the bottom of the shock absorbers were missing. However, since the holes at the bottom of the shock absorbers were either empty or packed with coral sand it was inferred that the hardened steel tips had fallen out and had not corroded away. Galvanic corrosion between mild steel and alloy steel is known to occur, but the absence of corrosion products from the holes in the bottom of the shock absorbers indicated that galvanic attack had not occurred. The coatings on the shock absorbers, where applied, were mechanically damaged in many areas and afforded little protection. Uncoated areas and areas at coating damage were similar in appearance.

The base plate holding the shock absorbers and the universal joint connecting the base plate to the main column were generally not rusted. However, at areas of mechanical damage and at a few localized areas of topcoat blistering there were loose flaky white corrosion products which were sampled and shown to be primarily $Zn(OH)_2$. Some minor rust bleeding from the shafts of the universal joint was noted in spite of the heavy coating of grease remaining at these areas. The main column up to the level of the cable bellmouth was unattacked, only a few areas of paint were blistered and no rust was noted at these areas. The coatings on the interior and exterior of the cable bellmouth were severely damaged and the topcoats of paint were gone from approximately 80% of the exposed area. White corrosion products later found to be $Zn(OH)_2$ were found at the areas of topcoat failure, however no red rust was noted.

The main column from the bellmouth to the bottom of the buoyancy sphere was unattacked. The topcoat of paint had blistered over about 5% of the exposed area. These blisters were filled with white corrosion products later found to be $Zn(OH)_2$. There was no attack of the steel under these blisters. It was noted that the yellow paint used to letter the main column and buoyancy sphere was virtually intact, no failures of this

coating were noted. The cable conduit which was bolted to the main column was unattacked. However, a few of the bolts used to attach the conduit to the column showed rust bleeding from underneath the sealant covering them. These bolts were found to be Type 304 stainless steel and the one sample removed showed slight crevice corrosion about .005" deep at the threads.

The buoyancy sphere was in essentially the same condition as in the first inspection except for more blistering of the topcoat of paint and the change in character of the rusting noted at two areas in the first inspection. The tightly adhering black oxide noted at these areas had changed to a loosely adhering red oxide of a more familiar character. This change is typical of steel which corrodes in an environment which is low in oxygen which is subsequently brought into an environment high in oxygen. The cable conduit at the sphere was unattacked as on the main column; however, rust stains at the sealant on two conduit clamp bolts were noted although these were not disturbed for further inspection.

The coating on the joint between the sphere and the steering carriage showed some small blisters scattered over a few small areas. These blisters were filled with white corrosion products. The rust bleeding noted at the joint faying surfaces had become more generalized. The paint coating on the steering carriage showed some minor blistering not noted on the first inspection. The rusting on the inside of the carriage stop housing flanges had become more pronounced.

Aluminum alloy keys and jacks were attached to the steering carriage after recovery in order to secure the antennas during the tow. After five days exposure these keys and jacks were covered with a rather thick coating of corrosion products. This attack was due to galvanic corrosion between the keys and jacks and the exposed steel areas on the tower.

The gas generator support structure showed more rusted areas than in the first inspection. This was especially noticeable at corners of the structural members where coating thickness was low. The gas generators showed no visible attack except as noted in the first inspection. The platinum gauze anode on the electrolytic gas generator was less clogged than in the first inspection indicating that the clogging was not extremely adherent.

The rust stains noted on the three antennas during the first inspection were reinspected. The thin, adherent black oxide scale has changed in appearance. These areas were now covered with a thicker coating of loose flaky red rust. Reinspection of the area on the low frequency antenna which was probed during the first inspection showed that this area was now covered by a thin layer of loose, flaky red rust. However, the pit underlying this rust had not increased measurably in thickness or extent.

Several of the gas connections between the ends of the compliant tubes and between the tubes and the gas manifolds showed some rust bleeding from underneath the sealant used to protect the connections. The connections showing rust were marked for further inspection. The antenna support arms now showed considerable rust staining, especially at areas of mechanical damage and at areas such as sharp corners and the interiors of the arms where the coating was thin.

The syntactic foam blocks of the foam tower and on the low frequency antenna remained unattacked. No additional coating damage was noted. The main lifting eye at the top of the foam tower was now covered with a loosely adherent film of flaky red rust.

Third Inspection

A third a final inspection of the tower was made after the tower had been lifted onto the dock for repair. This inspection was made over a two day period. During this period the appearance of many areas changed appreciably. Unless otherwise noted the descriptions in this section refer to the condition of the tower as noted on the second day, after the tower had been rinsed with a high pressure hose and allowed to dry.

The shock absorbers, as shown in Figure 3, were covered with loose, flaky red rust and rust stains. The surfaces under the rust were etched but no pitting was noted. The area under the missing hardened tip was as corroded as the adjacent areas on the cone, which indicates that the hardened tips were lost during emplacement. Areas under the undamaged paint coating were unattacked. The paint coatings showed no undercutting adjacent to damaged areas.

The coatings on the base plate and universal joint had blistered over about 10% of their surfaces. No rust under these blisters was noted. Areas of mechanical damage were covered with flaky red rust. Removal of this rust revealed little significant corrosion underneath. Fresh water rinsing of the base plate and universal joint resulted in the loss of about 10% of the black top coat of paint from the surface. No additional corrosion was noted at these areas of paint failure. The main column up to the level of the bellmouth showed about 10% of its area covered with blisters. Upon fresh water rinsing many of these blisters ruptured and top coat of paint was lost. No significant corrosion was uncovered by this coating loss. The bellmouth showed considerable rust staining and much of the top coat of paint on it was lost during fresh water rinsing. However, no significant attack of the bellmouth was noted.

The coating on the main column from the bellmouth to the bottom of the buoyancy sphere was blistered over about 10% of its surface. As on the lower portions of the main column and base the top coat of paint was lost during fresh water rinsing although no corrosion at these areas of paint

failure was noted. The yellow paint used to letter the main column and buoyancy sphere remained intact, even after fresh water rinsing. No significant paint failures or attack was noted on the cable conduit on this section of the tower. No additional rust bleeding from the sealant used on the conduit attachment fasteners was noted.

About 10% of the sphere was covered with blisters before rinsing. About half of these blisters ruptured upon rinsing and exposed the underlying primer. The rust at the areas of paint failures noted in the previous inspections was now loose and flaky. The pit noted in the first inspection (as shown in Figure 4) was accurately measured and found to be a maximum of 0.110" deep. No other significant corrosion was noted. The coating on the joint between the sphere and the steering carriage was blistered and these blisters ruptured upon being rinsed. No corrosion under the ruptured blisters was noted. The rust staining at the faying surfaces of the joint remained after rinsing. The coating on the steering carriage was now moderately blistered as shown in Figure 5. However, no rust staining of the primer underneath these blisters was noted when the blisters ruptured upon rinsing. The rusting at the carriage stop housing flanges was now loose and flaky. Loose flaky rust around one fastener on the flange was noted and is shown in Figure 6. The altitude indicator, as shown in Figure 7, was readable even with the loss of a significant amount of paint coating. The aluminum alloy keys and jacks used to secure the steering carriage were covered with a thin superficial film of corrosion products, as shown in Figure 8. Attack of these areas was superficial and was essentially arrested after the tower was removed from the water.

The gas generator support structure, as shown in Figure 9, had loose flaky red rust at the edges of the metal frame members. Only superficial corrosion was found associated with this rusting. The titanium cathode on the electrolytic generator, as shown in Figure 10, was unattacked. The platinum anode was also unattacked. The remaining fouling on the platinum anode was easily removed by fresh water rinsing.

Figures 11 through 14 show the results of inspection of a typical rusted area on the middle frequency antenna. Figure 11 shows the area covered with a loose flaky red rust deposit. Figure 12 shows the area after removal of the deposit. Figure 13 shows the defects in the coating which resulted in the attack. Figure 14 shows the area after removing the coating. Note the feathered edge of the coating in Figure 14. Only three coats of paint are present. A red primer, white second coat and gray topcoat. No zinc rich primer was used on this or any other rusted areas of the compliant tubes. Brushmarks in the coatings at the rusted areas indicated that the coatings had been "touched up" at these locations without using the zinc rich primer. Removal of the upper coats of paint in an unattacked area of the low frequency antenna showed that the zinc rich primer was present.

The rust stains on the gas connections were found to originate primarily from the mild steel clamps used to secure the flexible tubing to the steel nipples. No significant attack of the tubing, tubing clamp or nipples was noted. No significant attack on the antenna support arms was noted although voluminous loose flaky red rust was present in many areas of paint failure. The attack under the rusted areas was uniform.

The condition of the syntactic foam blocks of the foam tower is illustrated in Figure 15. Although the coating at the identifying letter had failed, the underlying material was unattacked. No signs of water absorption or deformation of the foam blocks of the foam tower, low frequency antenna or gas generator support was noted. The main lifting eye at the top of the foam tower, as shown in Figure 16, was covered with a thin film of loose flaky red rust but no significant corrosion was noted underneath the rust layer.

Repair of Tower

Echo tower was to be reemplaced if its condition permitted. As the damage resulting from emplacement and retreival was minimal and the amount of corrosion found did not preclude reemplacement, the tower was repaired. The four shock absorbers were replaced with similar units. However, the tips on these units were screwed into place in contrast to the pressed-in units originally used. These screwed-in tips were further secured by welding and are shown in Figure 17. The universal joint was relubricated. The tower base, universal joint, main column and buoyancy sphere were cleaned by an air powered high pressure water jet and recoated with a copper oxide-pigmented rubber-based antifouling topcoat. The yellow enamel identifying marks were reapplied after the antifouling coat had cured. The condition of the buoyancy sphere after repair is shown in Figure 18. The fasteners used to secure the cable conduit to the main column were recoated as required with a rubber based sealing compound. Rusted areas on the steering carriage and antenna support arms were cleaned and recoated with a two coat, polyamide-cured epoxy paint system. The gas generators were replaced. The attacked areas on the antennas were carefully sanded and cleaned before recoating with the same paint system. The gas connections between the ends of the compliant tubes and the gas manifolds were cleaned, the clamps and tubing replaced as necessary and recoated with a two component sealing compound where any rust staining of the connections was noted. Areas of paint failure on the foam tower were repaired using the topcoat of the polyamide cured epoxy paint system. Identifying marks were reapplied to the foam tower. The recoated foam tower is shown in Figure 19. The main lifting eye was cleaned, and then recoated with the two coat polyamide cured epoxy system. The tower was then considered to be ready for reemplacement.

CONCLUSIONS

Many important deterioration protection principles were incorporated in the design of the ECHO tower of the Azores Fixed Acoustic Range. In critical areas such as the steering carriage shaft seals, materials known to be immune to corrosion were used. In non-critical areas materials subject to only uniform attack were used and these materials were protected over the majority of their surfaces by the use of protective coatings, especially by the use of zinc rich primers. Such primers afford galvanic protection to the underlying steel should the barrier film of the topcoats be ruptured. For components such as the gas generator valves and the carriage lock jacks and keys, where their long term corrosion resistance was insignificant, materials selection was based upon other considerations.

In a few areas, however, considerable improvement in the long term reliability of the tower could be realized.

The use of sealants to prevent corrosion of materials subject to crevice corrosion is not reliable. Such a system was used on the fasteners used to attach the cable conduit to the main column. Only one fastener was removed from this area and it had corroded to a depth of .005" due to crevice corrosion. This attack was not critical, however, as the number of fasteners used would allow the failure of many before the conduit attachment would be jeopardized.

Another area of potential failure was the attack noted on the antennas. Pits on the 1/16" thick material of high frequency compliant tubes had progressed to near penetration in a few areas. Such penetration would cause the loss of gas which would result in antenna failure. All the pits noted in the antennas were at areas of paint repair where no zinc rich primer was applied. These pits were considered to be the most severe attack noted on the tower in terms of system reliability. All other attack noted was insignificant in terms of system reliability when compared with the pits on the antennas.

The additional lifetime of the tower when reemplaced depends almost entirely on the attack on the antennas. If the pits already present reinitiate and penetrate still further the useful additional life of the tower may be as little as one year. However, if the recoating of these areas is successful and corrosion occurs at other areas the additional useful lifetime of the tower will depend on the thickness of the material on the antenna attacked. The 1/16" thick material of the high frequency antenna could last as long as five years and the others proportionately longer.

RECOMMENDATIONS

These recommendations apply to both the modification of the existing towers in the event they are recovered and subsequently reemplaced and to the building of other similar structures.

1. The use of only uniformly corroding materials which are subsequently coated should be continued. The stainless steel fasteners on the existing towers need not be replaced unless very long lifetimes are required although the use of such materials in future towers is not recommended.

2. The use of materials known to be immune to corrosion in critical areas is recommended.

3. Repair of coating systems with identical systems is recommended.

4. The addition of a cathodic protection system to such a structure would greatly increase its useful life and is recommended.

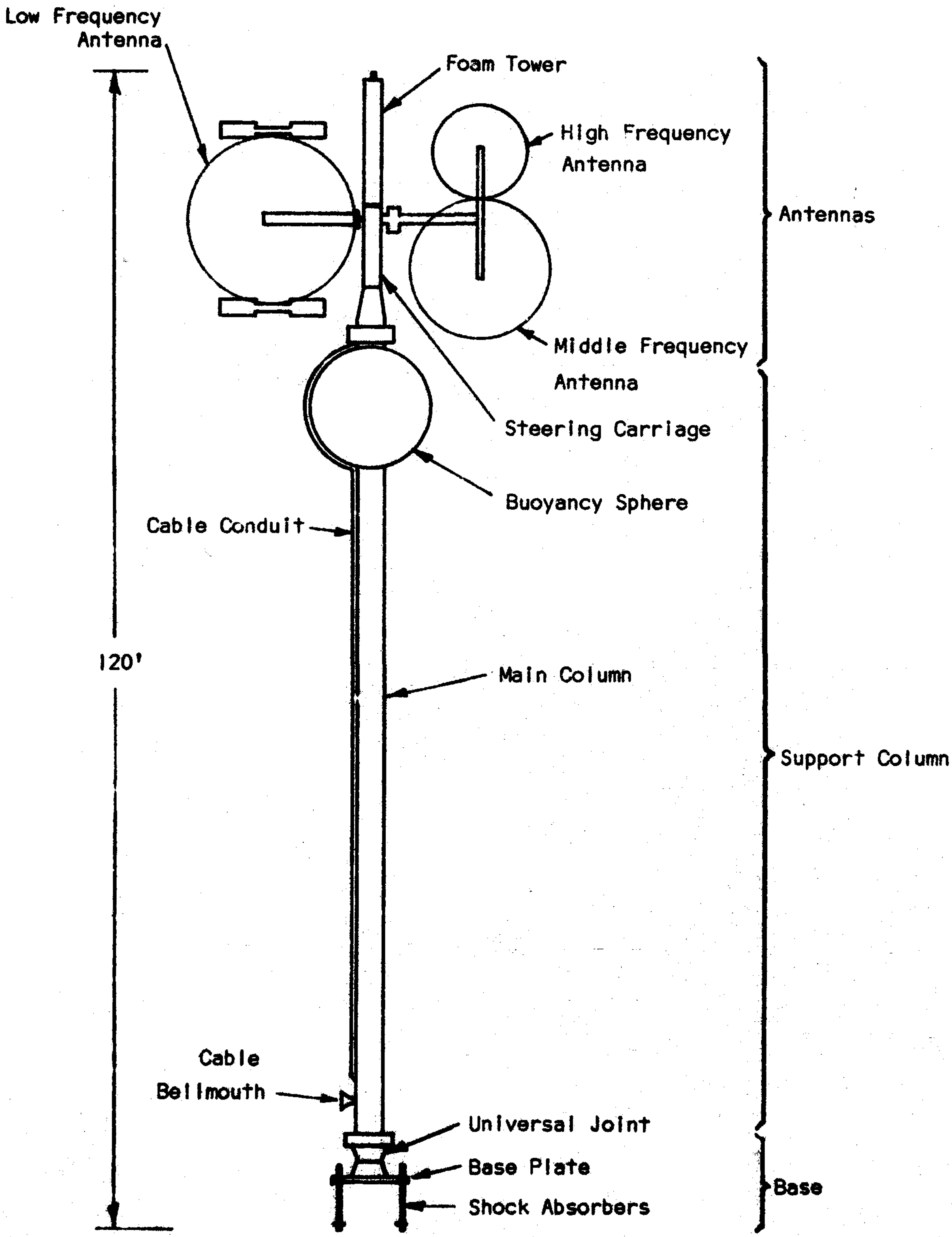

Figure 1. Sketch of Tower.

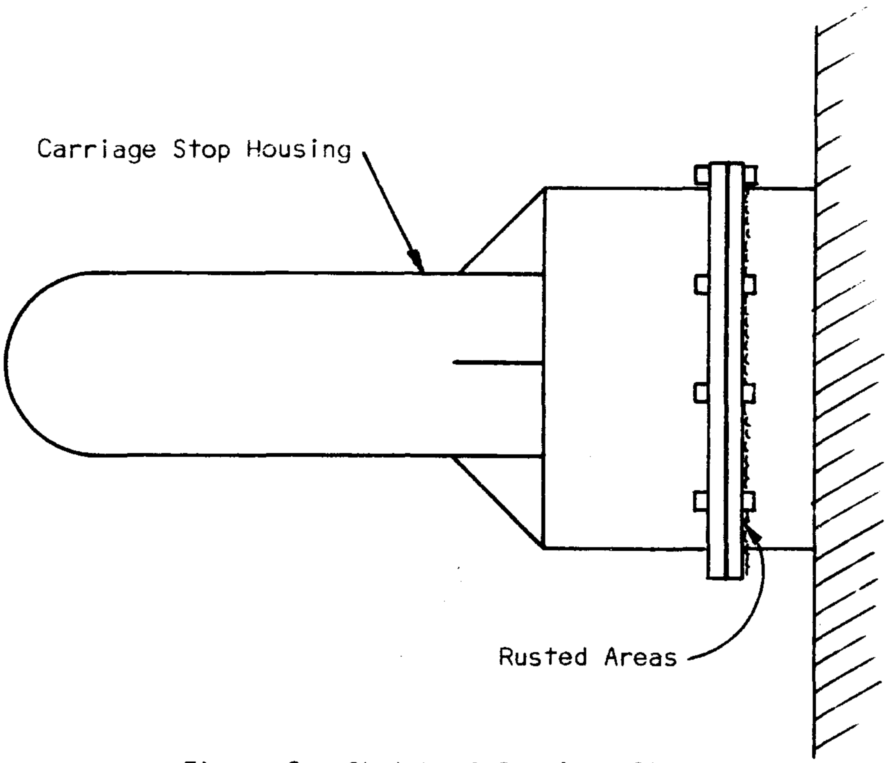

Figure 2. Sketch of Carriage Stop.


Figure 3. Shock Absorber.

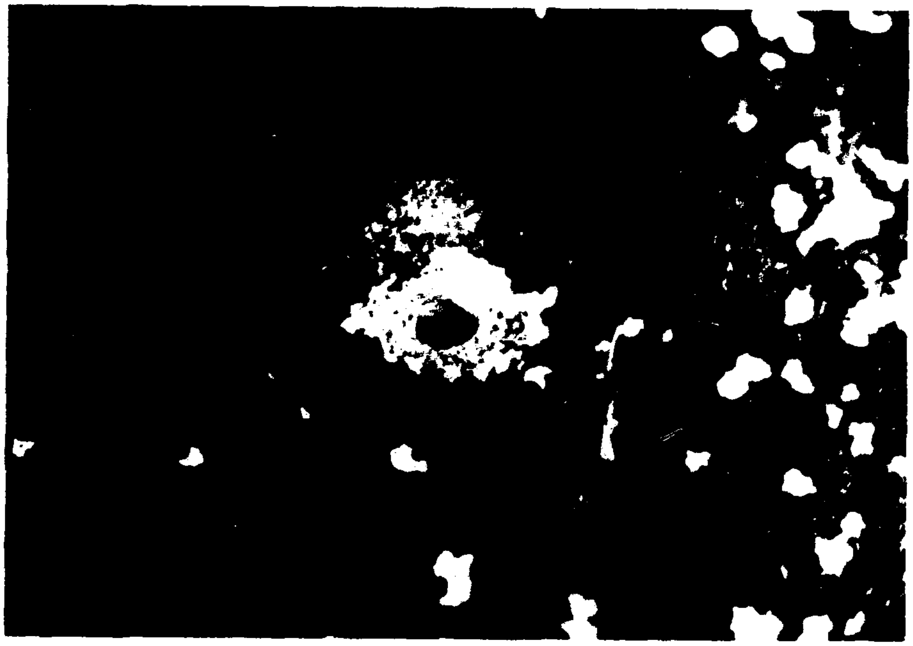

Figure 4. Pit on upper portion of buoyancy sphere.

Figure 5. Blisters on steering carriage.

Figure 6. Fastener on carriage stop housing flange.

Figure 7. Altitude indicator.

Figure 8. Carriage lock keys and jacks.

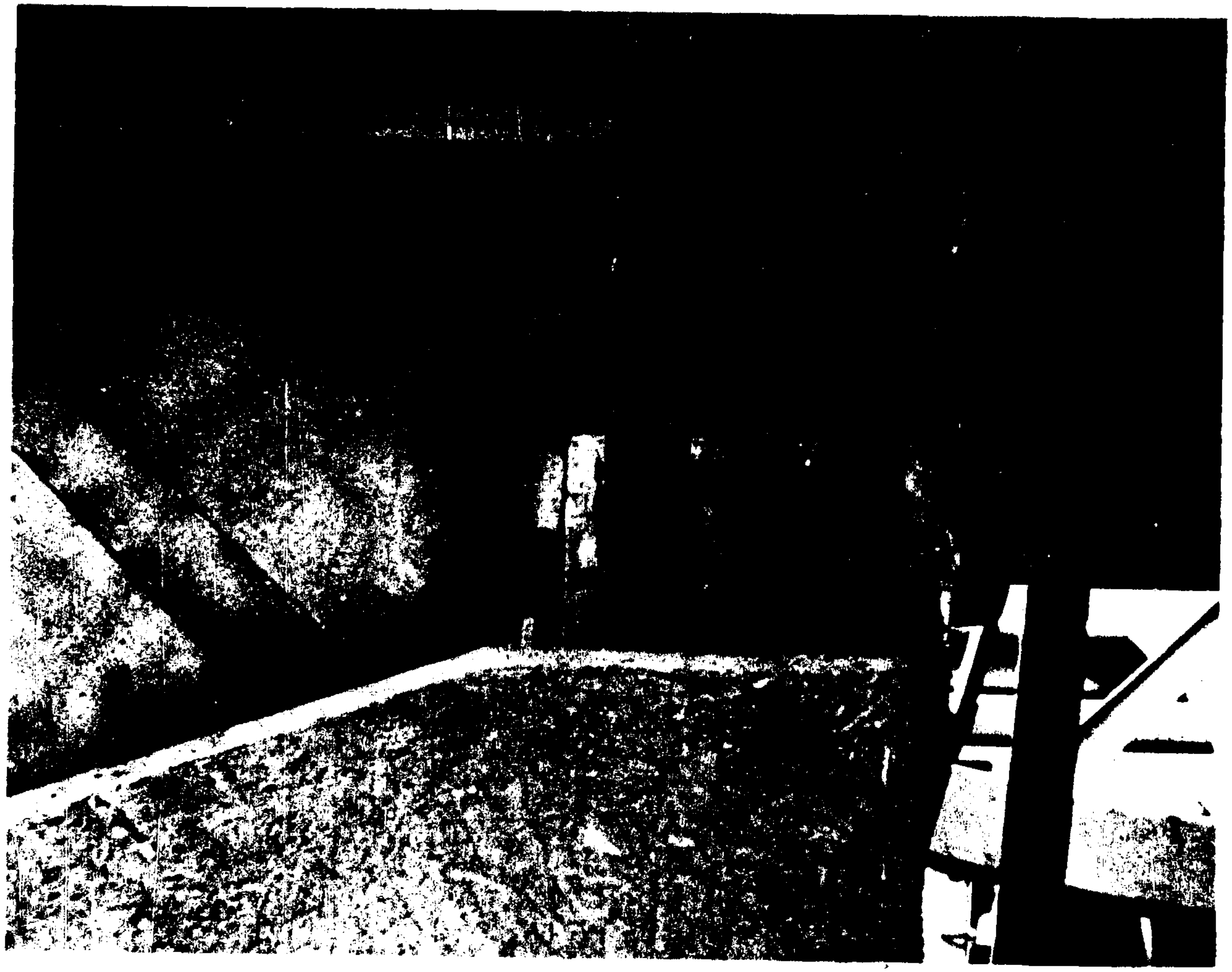

Figure 9. Gas generator support structure.

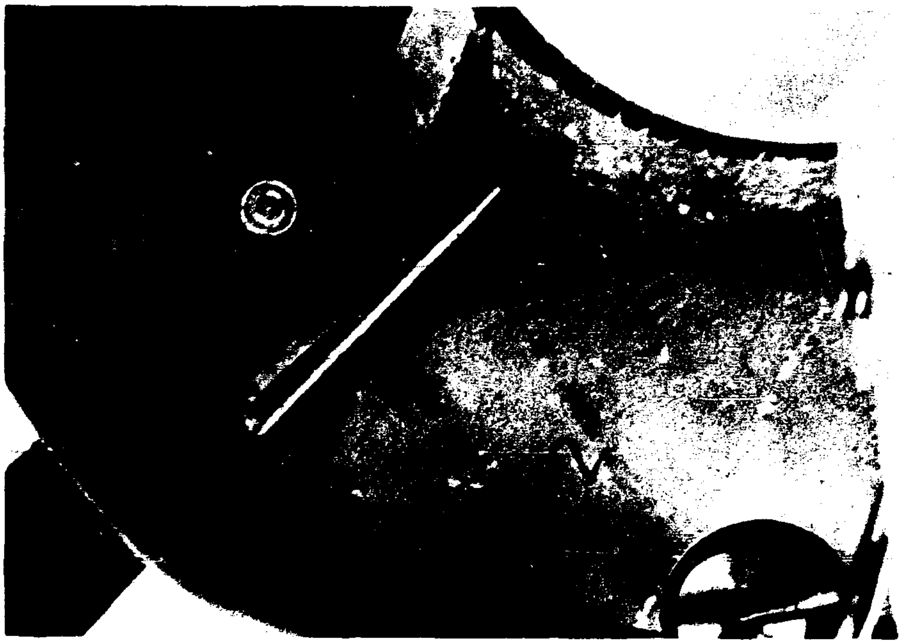

Figure 10. Electrolytic gas generator cathode.

Figure 11. Rusted area of middle frequency antenna.

Figure 12. Area shown in Figure 11 with rust removed.

Figure 13. Same area as in Figure 11 with rust staining removed.

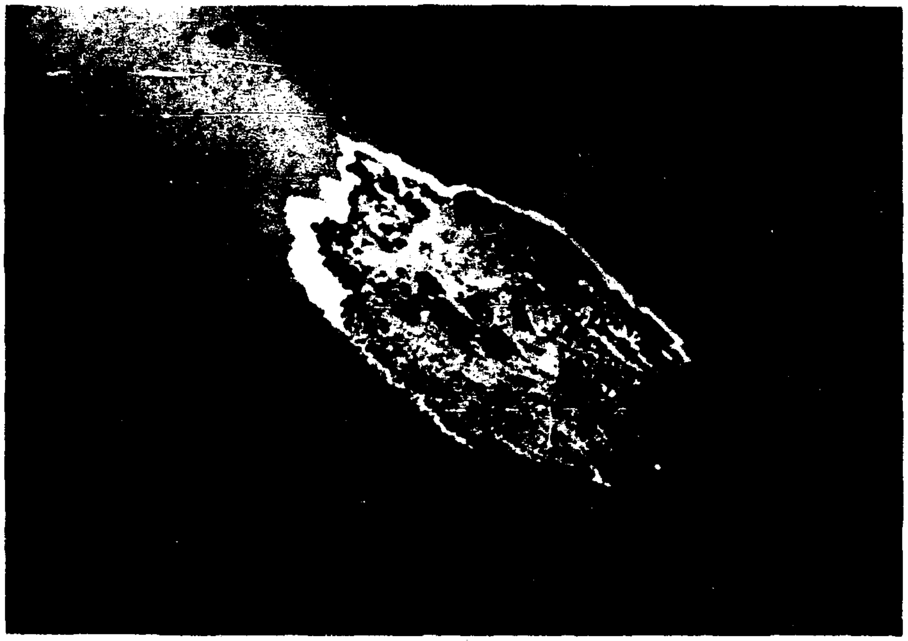

Figure 14. Same area as in Figure 11 with coating removed.

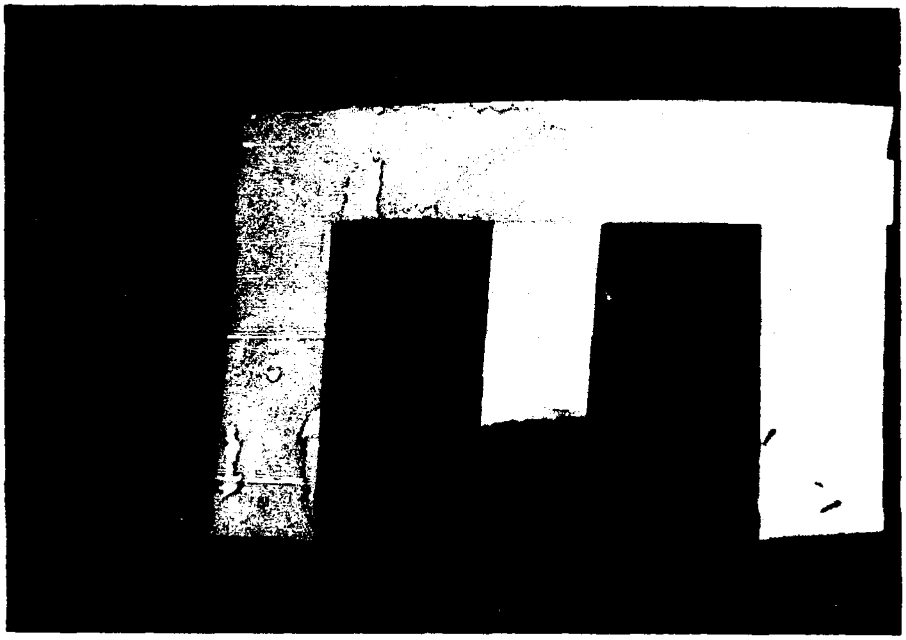

Figure 15. Portion of foam tower.

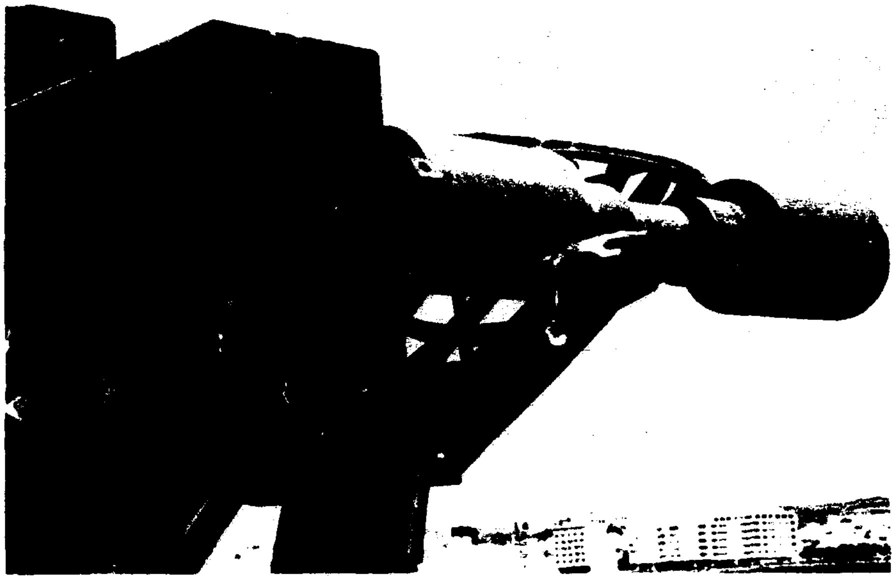

Figure 16. Main lifting eye at top of foam tower.

Figure 17. Modified shock absorber tip.

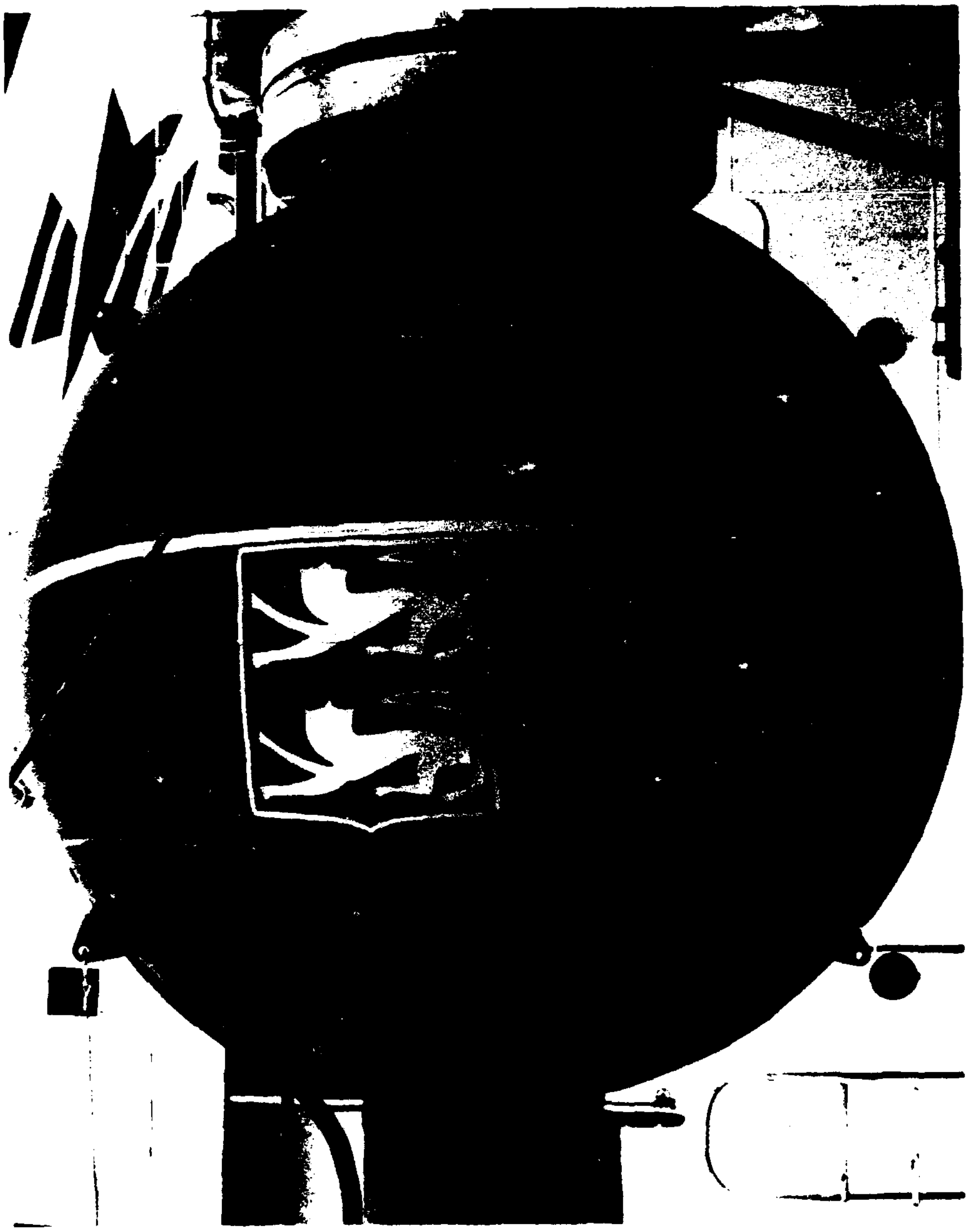

Figure 18. Buoyancy sphere after recoating.

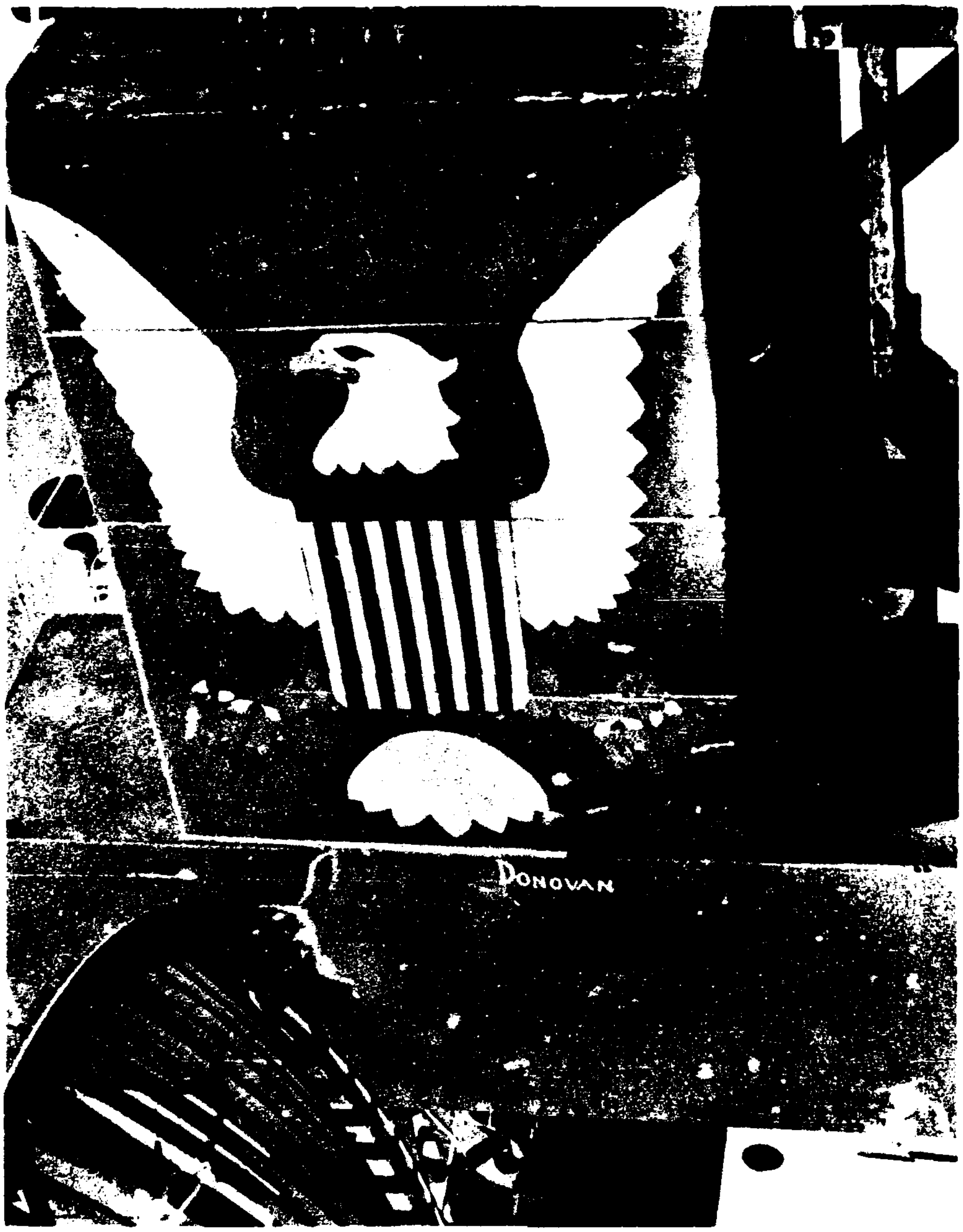

Figure 19. Foam tower after recoating.